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An Evaluation of COVID-19 in Italy: A data-driven modeling analysis

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ABSTRACT

The novel coronavirus (COVID-19) that has been spreading worldwide since December 2019 has sickened millions of people, shut down major cities and some countries, prompted unprecedented global travel restrictions. Real data-driven modeling is an effort to help evaluate and curb the spread of the novel virus. Lockdowns and the effectiveness of reduction in the contacts in Italy has been measured via our modified model, with the addition of auxiliary and state variables that represent contacts, contacts with infected, conversion rate, latent propagation. Results show the decrease in infected people due to stay-at-home orders and tracing quarantine intervention. The effect of quarantine and centralized medical treatment was also measured through numerical modeling analysis.

Introduction

In December 2019, an unprecedented outbreak of pneumonia with an unknown cause occurred in Wuhan, capital of Hubei province in central China. A novel coronavirus was identified as a pathogen, which named covid-19 by the World Health Organization (WHO) subsequently¹. It spans a long incubation period and has highly infection among human beings². Currently, the confirmed cases of COVID-19 are up to 2,810,325 and 193,837 fatality cases occurred in global as of April 26. The heavy shock has burdened more than SARS and Middle East respiratory syndrome (MERS), which happened in 2003 and 2013, respectively. Under the strict large-scale prevention and control mechanism, new cases of COVID-19 have decreased rapidly in China. But 1,341,851 cases still occurred in Europe and 1,094,846 in Americas as of April 26. The new cases are on the up road, which brings severe challenge to health security in the world.

The outbreak has hit Europe, it reports more than 24,000 cases in Italy by mid March from Center for Systems Science and Engineering at Johns Hopkins University, and increased rapidly in the following days, where became the second-largest number of confirmed cases since March 20,2020. Limited capacity of hospital care burdened the Italian health system heavily. Modeling research from Remuzzi A and Remuzzi G³ overestimated the number cases but a severe lesson has been presented by Andrea Saglietto et.al.⁴. The effective models can describe the real data and predict the trend, such as SEIR model, what had been used to simulate the different preventing duration and different control intensity via parameters for COVID-19 epidemic in Wuhan city^{5,6}. But Nicholas P. Jewell deemed that the primary and most effective use of epidemiological models is to estimate the relative effect of various interventions in reducing disease burden rather than to produce precise quantitative predictions⁷. In our opinion, estimates that emerge from modeling studies are not only validating to the epidemiological or statistical analysis for the real data⁸, but also assessing the effectiveness and efficiency of the isolation and containment measures proposed by the government, especially to the unpredictable cases, such as the presence of asymptomatic infected patients, which is a big challenge to fight against COVID-19⁹.

It seems exponential model is not suitable to the Italian situation. We tried the SEIR model and modified its parameters' system according to this country lockdown state and considered asymptomatic cases since the similar SIR model was applied in the process of interpretation to prevent and control COVID-19 in China, where achieved overall victory Since mid March¹⁰. Euler numerical calculation was employed to solve it. Real data from official website of Italy proved the effectiveness of prevention and control measures such as isolation and centralized hospital via our data-driven model.

Materials and Methods

Materials

The real data used in this article are from the official website of the Italian Ministry of Health (<http://www.salute.gov.it/nuovocoronavirus>). At the local time on March 9, 2020, Giuseppe, the Prime Minister of Italy, held a press conference to announce the great pressure of the epidemic prevention and control, and signed an order to extend the isolated districts to the whole country. We aimed to assess the isolation effect of this country, so the modeling-driven data started from

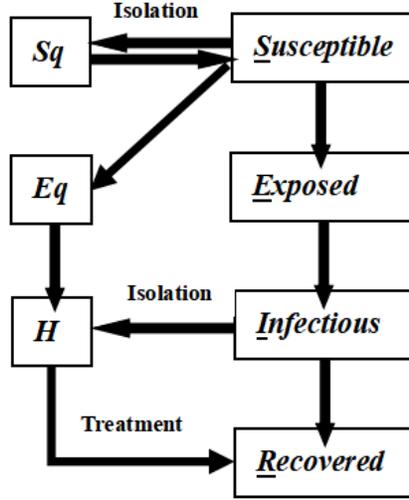


Figure 1. The SIER flow diagram. Flows represent per capital flows from the donor compartments

the lockdown day of March 10.

Methods

It is well-known that COVID-19 is complicated and changes its type according to race and district difference¹¹, and limited to capture the feature by the classical SEIR model, which is used to modeling the infectious disease¹². Here we combine the measurement of testing, isolating and hospital care process, and then divide the total cases into several parts noted as susceptible (S), exposed (E), infected (I), recovered (R), susceptible quarantine in home (No symptoms or no critical case in home for isolation, names as S_q), quarantine spreader (E_q) and hospitalized patients (H). The transformation relationship of the population is shown in Fig. 1.

We denoted q as the proportion of isolation, β as the probability of infection, c as the contacting rate, and ρ as the effective contact coefficient for value 1 according to the literature¹³. The percent conversion from S to S_q , E_q , and E are $\rho c q(1 - \beta)$, $\rho c \beta q$ and $\rho c \beta(1 - q)$, respectively. There exists some abnormal circumstance that mild cases from the group of infected S_q have been infected again, so we add the information of positive-testing cases I and ambushing cases E for the influence to susceptible group. Then the controlling function of susceptible cases is described in (1).

$$\frac{dS}{dt} = -[\rho c \beta + \rho c q(1 - \beta)]S(I + \theta E) + \lambda S_q \quad (1)$$

where θ is the ratio of the latent to the infectious cases; Suppose that patients with latency have the same infectious capacity as those who have shown symptoms, i.e. $\theta = 1$. λ is the releasing rate from isolation, we denote $\lambda = 1/14$ since The isolation time was 14 days. The modified SEIR kinetic equation for covid-19 outbreak has been constructed as shown in (2).

$$\begin{cases} dS/dt = -[\rho c \beta + \rho c q(1 - \beta)]S(I + \theta E) + \lambda S_q \\ dE/dt = \rho c \beta(1 - q)S(I + \theta E) - \sigma E \\ dI/dt = \sigma E - (\delta_I + \alpha + \gamma_I)I \\ dS_q/dt = \rho c q(1 - \beta)S(I + \theta E) - \sigma S_q \\ dE_q/dt = \rho c \beta q S(I + \theta E) - \delta_q E_q \\ dH/dt = \delta_I I + \delta_q E_q - (\alpha + \gamma_H)H \\ dR/dt = \gamma_I I - \gamma_H I \end{cases} \quad (2)$$

where σ is the conversion rate from the latent to infected case and $\sigma = 1/14$; α is fatality rate, δ_I is the speed rate of isolation, γ_I is the recovery rate of infection, δ_q is the transferring rate from the isolated lurker to isolated infectious case, and γ_H is the recovered rate of infection.

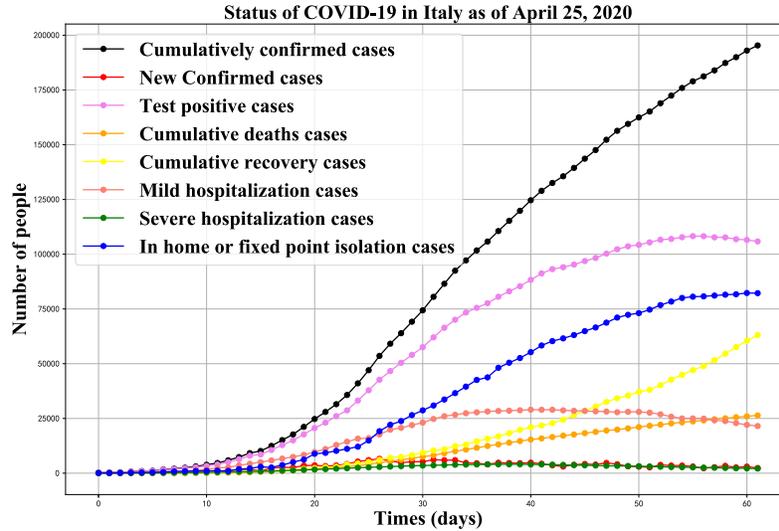


Figure 2. Epidemic curves for Italy, with infectious situation from February 24 to April 25, 2020

Here we chose the Euler numerical method to solve the equation group (2), and the integral step is set as 0.01. The initial parameters setting are listed as Table 1.

Results

Since the first indigenous case was confirmed in the northern Italy on February 21, a red zone, was instituted in the next day, which put on lockdown to prevent the emerging threat. On March 9, The entire country was declared as red zone. It shows in Figure 2 the infectious situation from February 24 to April 25. The inflection point of newly confirmed cases has emerged in March 26, which is the peak with 6153 increased cases and then drop down. The number of minor and severe hospitalizations has decreased after 41 days of lockdown. The increasing speed of cumulative number for confirmed cases has slowed down since April 11, which is consistent with the effect of second stage for prevention and control measures(Fig. 2).

Table 1. The description and initial setting of variables and parameters.

Varialbes	Setting	Explanations
S	60482200	Italy's population as of March 2020.
E	17831	The difference between the number of diagnosed cases on March 10 and March 16, 2020.
I	8514*1.5	The undetected number on March 10.
S_q	2936	Number of patients who tested positive for nucleic acid on 10 March but underwent isolation without symptomatic manifestations.
E_q	423	Less than S_q .
H	13194	Less than $I + E_q$.
R	1004	Official data.
Parameter	The value	Explanations
c	2	According to lockdown time.
δ_I	0.018	Real data's estimation.
δ_q	0.13	Literature [10].
γ_I	0.006	Deduced form real data.
γ_q	0.017	Literature [10].
β	$2.05 * 10^{-9}$	Deduced form real data.
q	$1 * 10^{-6}$	Deduced form real data.
α	$1 * 10^{-4}$	Deduced form real data.

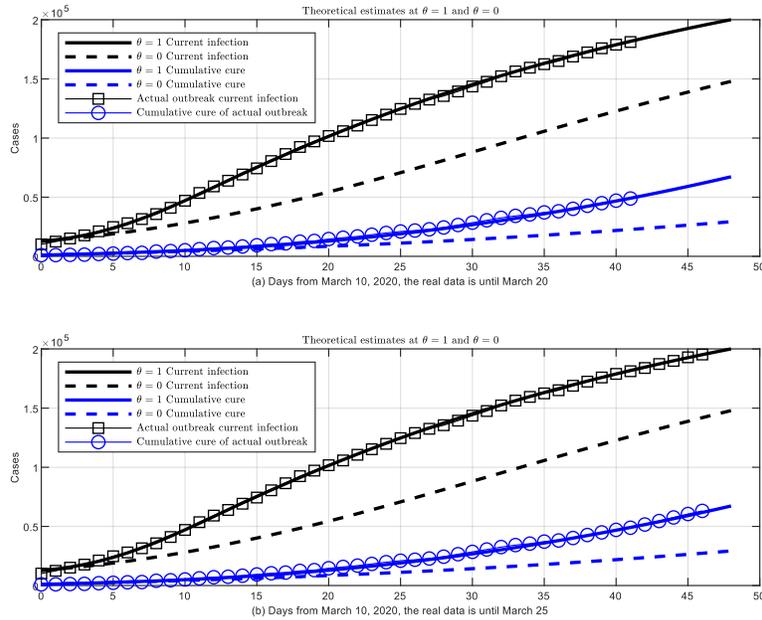


Figure 3. Theoretical estimates of the modified SEIR dynamics model with(a) and without(b) the infection of incubation period

The infectivity of incubation on the number of confirmed and recovered cases

Suppose the infectivity of patients in incubation period is set by the parameter θ , and the real data fitting is coincident with the theoretical model as $\theta = 1$, which had shown 0.0162 of Mean Absolute Percentage Error. It is well concluded that the theoretical estimation of the epidemic situation by the modified SEIR model is consistent with the actual situation in Italy (see Fig. 3(a) for details).

It should be pointed out that the model and parameters were set according to the data before April 20. We chosen the verified data set of confirmed cases from April 21 to April 25, which shown that the fitted data from our model is consistent with the real data as the mean absolute percentage error is lower than 0.0147 (see Fig. 3(b) for details). The modified model is successful to describe the characteristics of infection trend in Italy, and the infectious number of new cases will be expected to smoothly decrease by 30 April from the model prediction.

Influence Estimation to containment and isolation of close contacts on the outbreak

In the theoretical analysis, it is assumed that the close contacts under the current prevention and control isolation condition is 2. Here we simulated the infectious trend under inadequate prevention strategy through increasing the exposure rate, which is an effective measurement to access the lockdown effect. When the probability of exposure to susceptible cases is changed, the level of epidemic prevention and control has changed accordingly (assuming no change in diagnostic criteria). It concluded that that the current strict control and prevention and quarantine measures have produced a good inhibitory effect to prevent the epidemic expanding (Fig. 4).

We suppose that the rigorous medical tracking isolation is carried out in Italy, which means the isolation should be taken for 14 days to those people who are in contact with the infected cases. In order to measure the influence of this circumstance, here the infectious rate varies as 0.9, 0.8 and 0.6. It is evident that both the increasing rate and the peak of infections will increase correspondingly (assume that the diagnostic criteria have not changed), especially to the point of 0.6, the peak number of confirmed cases have increased over 1.6 times more than the original number (Fig. 5).

Assessment of the impact of centralized isolation and personal quarantine

The first temporary shelter hospital was operated in the city of Cremona on March 20; an exhibition centre was transformed into vulcan mountain hospital in ten days for supporting the creaking health system of serious infected Milan on March 30.

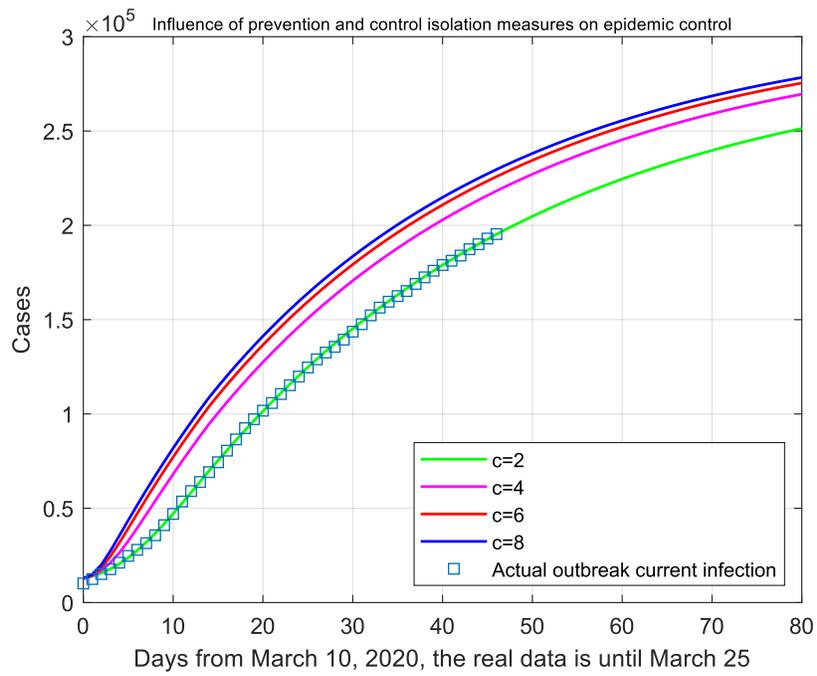


Figure 4. The impact of containment measures on outbreak control from modified SIER

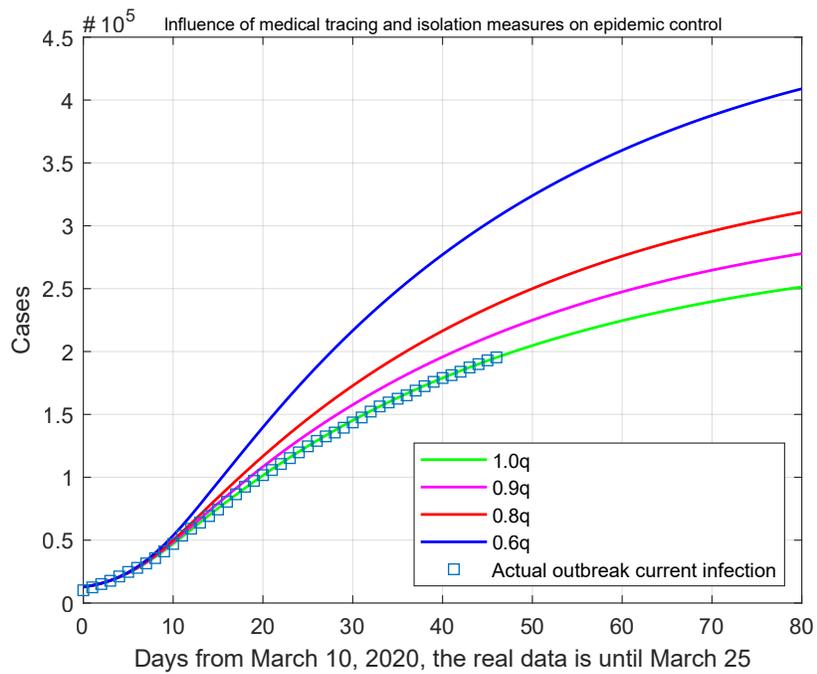


Figure 5. The impact of Medical tracking measures on isolation and control

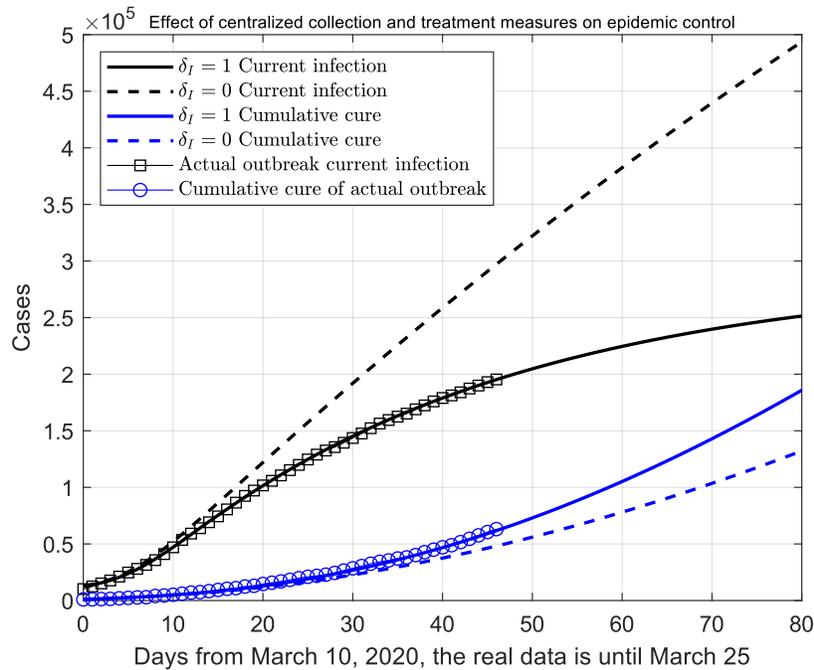


Figure 6. The impact of centralized isolation and personal quarantine

Intensive treatment of infected patients has been launched in Italy.

The pseudo trend of infected number was simulated under no concentrated treatment (Fig. 6). The conversion rate from infected to inpatient corresponds to the parameter δ_I in the model (2). The capacity of centralized treatment is proportional to δ_I . The rate of increase in the number of infected cases has declined after 50 days, which shown that the strategy of concentrated treatment is critical to slowing the rate of new cases in Italy.

Besides, the proportion of people in contact with infected cases should also be measured. Suppose the effective contact rate is $c' = \rho c$, where c is the daily contact rate, and ρ is the effective contact coefficient. The real data suggested the value of ρ is 1. Here we set the parameter ρ as 0.5, 0.25 and 0.1 respectively, which concluded that the smaller the contact coefficient, the less contact people with each other, then the smaller cases from the infection (Fig. 7).

Updated findings suggest that the best measure is persistent and strict self-isolation. The epidemics will continue to grow, and can peak soon with the peak time depending highly on the public health interventions practically implemented¹⁴. Steffen E. Eikenberry found that masks are useful for preventing illness in healthy people and preventing asymptomatic transmission¹⁵. Therefore, personal protection from the risk of infection is very important in curbing the epidemic extension. Strict daily precautions can make the peak time earlier and reduce the infectious number.

Discussion

Effective Models have contributed vital insights into the COVID-19 pandemic, which can help evaluate and predict the effect of the implementation of different guidelines and protocols through changing parameters. We have measured the transmission capacity of potential cases and intervention of follow-up isolation, which shown the lockdown strategy effective.

The theoretical analysis of the model shows that public awareness of prevention and control, medical follow-up isolation and adequate medicine care are critical to the spread of the epidemic. Centralized treatment played a key role in the rapid decline of the peak number of infected people. The prevention and control measures of covid-19 in Italy have been considerable for both symptomatic and asymptomatic people were screened.

We have opened a window to evaluate the effect of public health intervention and expect to search the faster way to prevent the virus. Italy is a good mode in this process. But there needs some future avenue of the work since covert transmission may be the main mode of spread, and its role is severely underestimated, which may be still on the risk of a second epidemic peak in global.

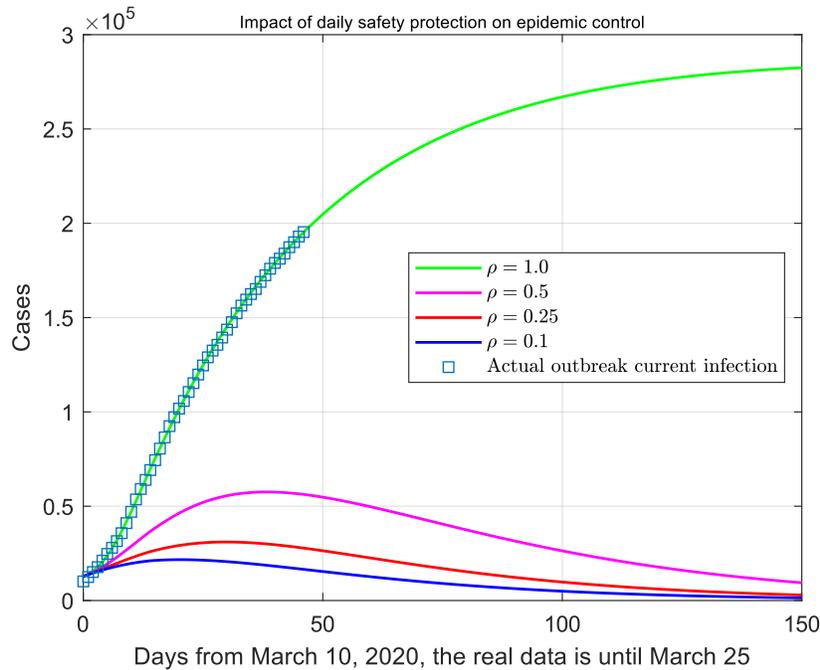


Figure 7. The impact of daily safety precautions on outbreak control

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None

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Contributions

YD wrote the main manuscript text and LG prepared figures 1–7. All authors reviewed the manuscript.

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Ethics declarations

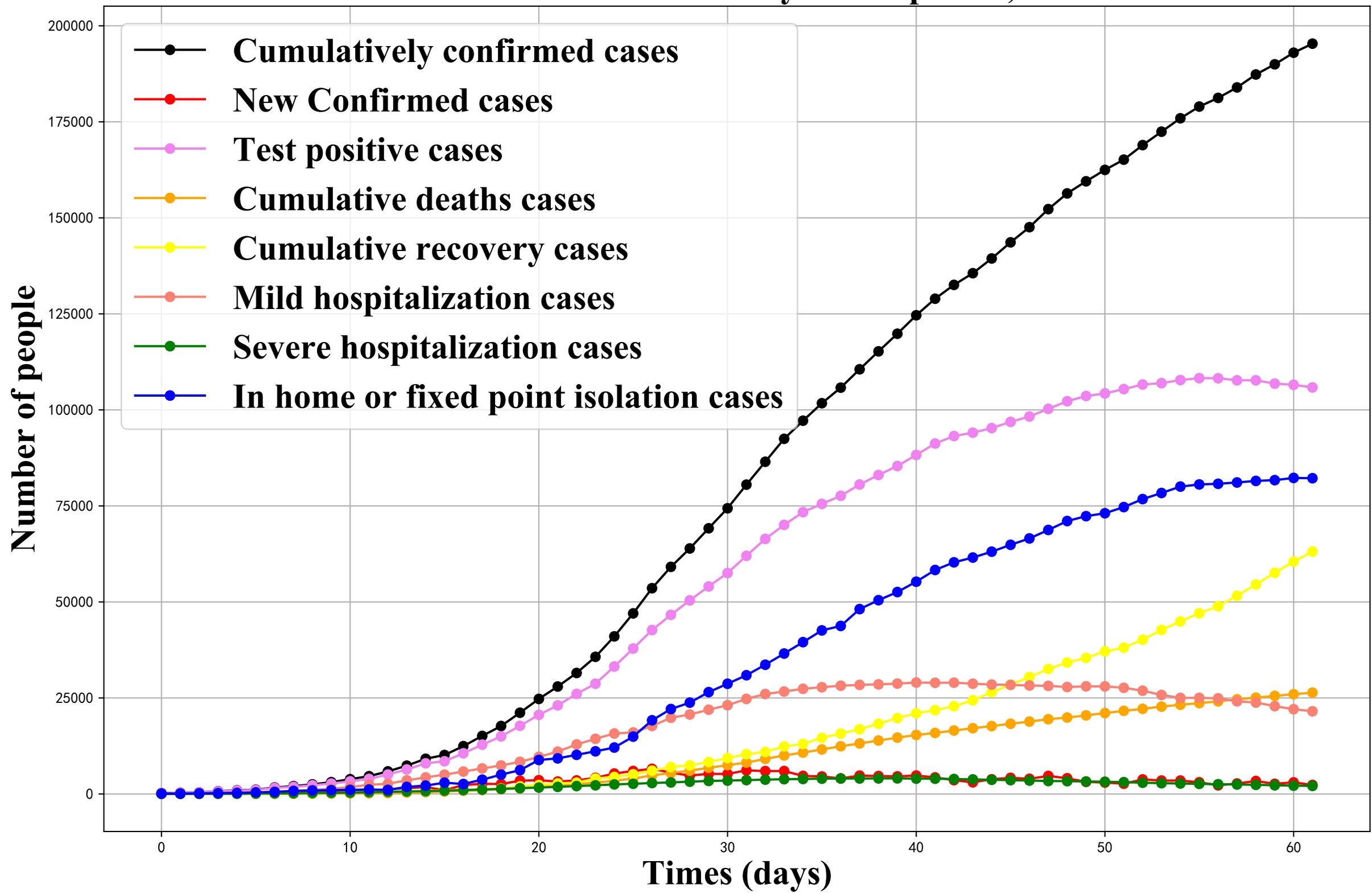
Competing interests

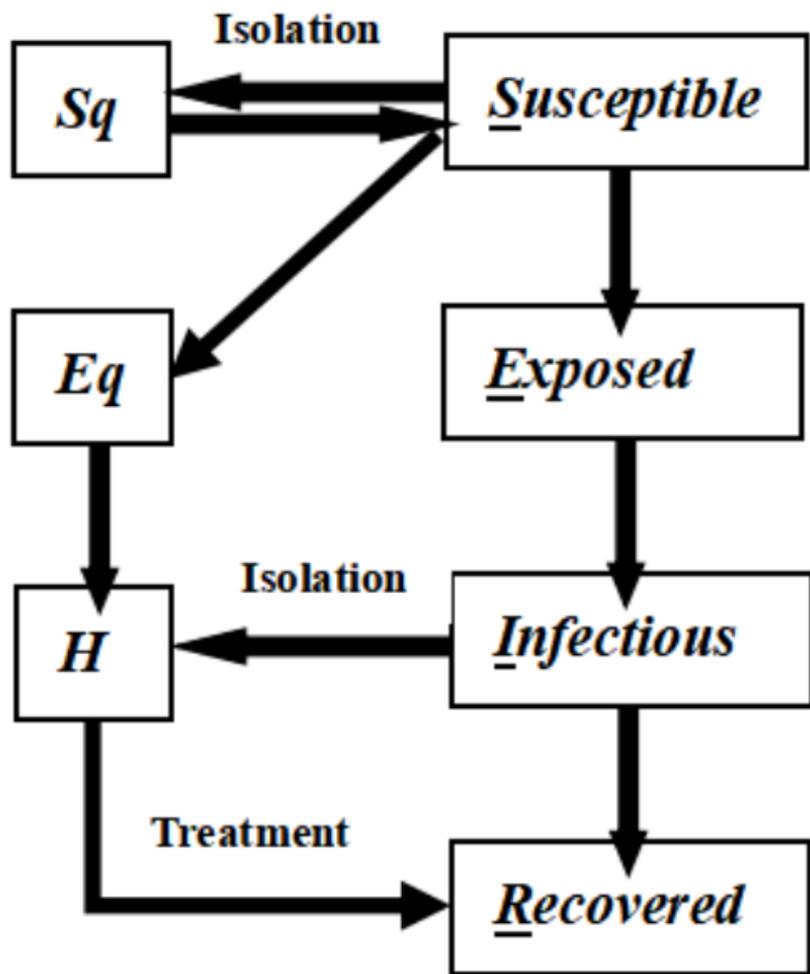
The authors declare that they have no competing interests.

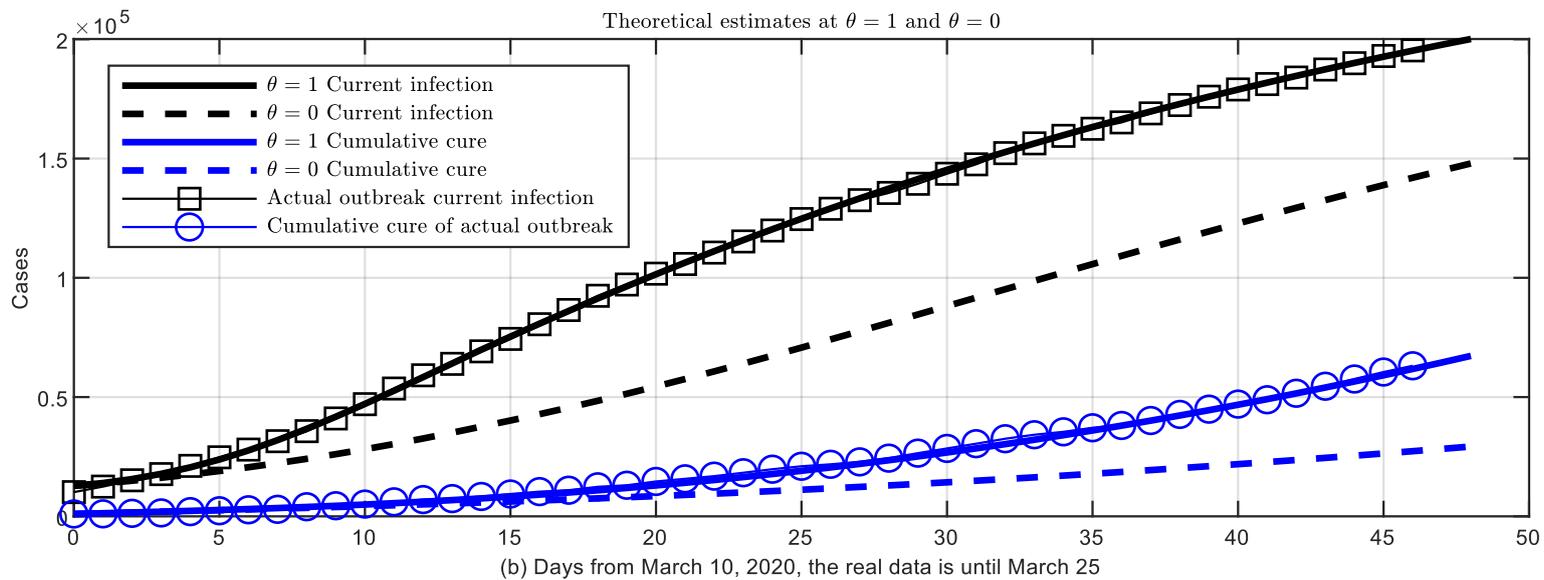
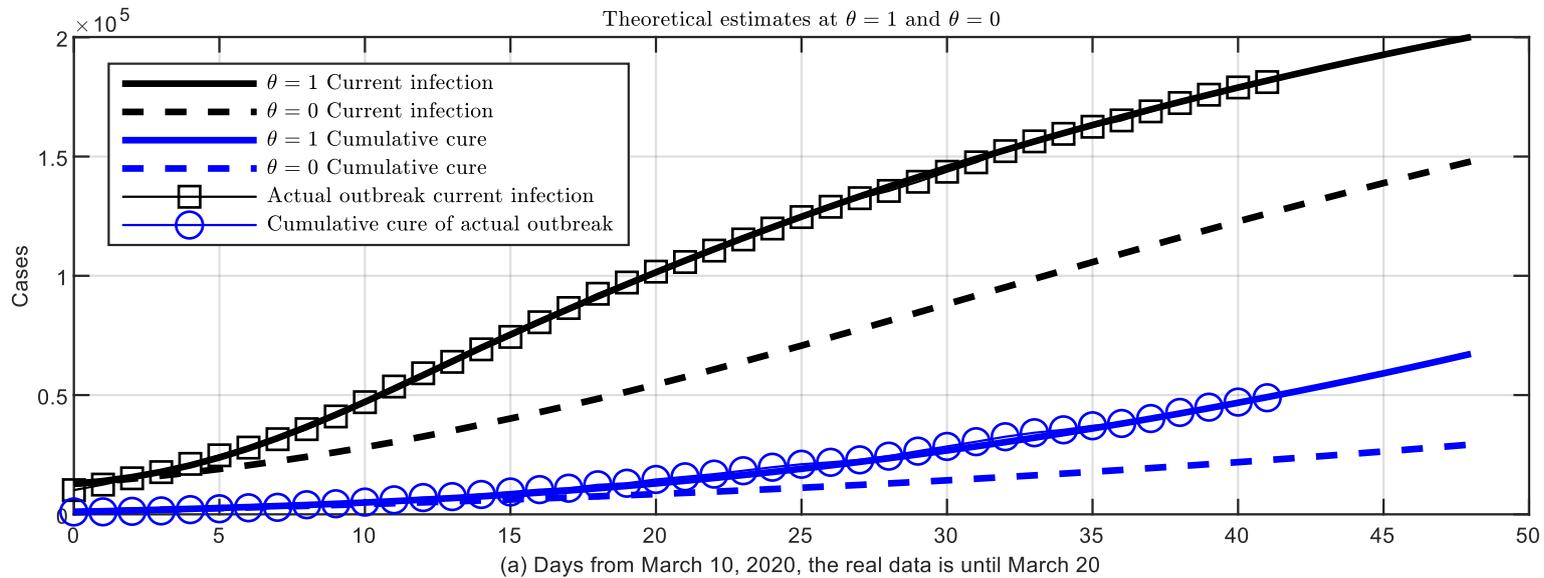
Additional information

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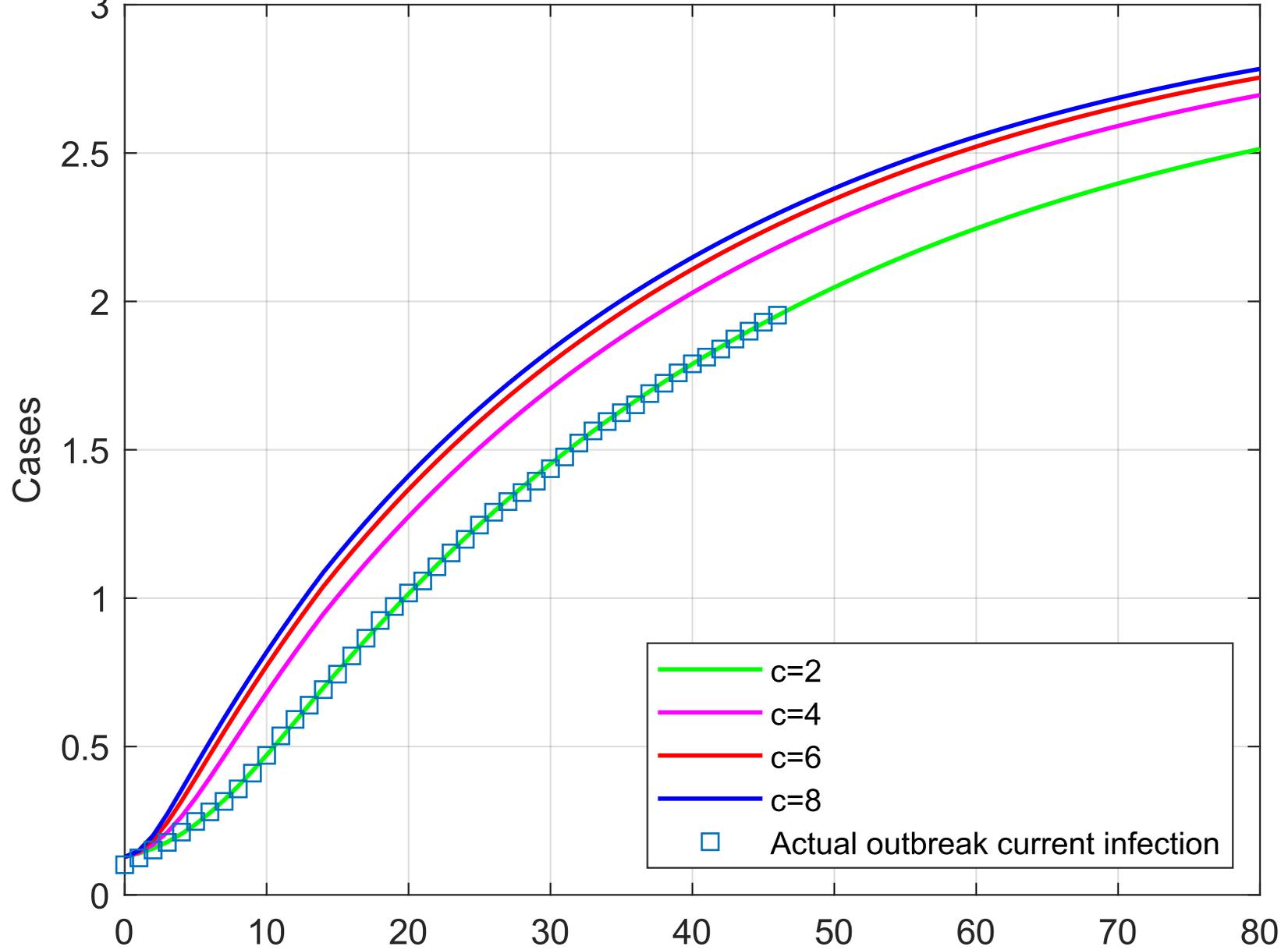
Status of COVID-19 in Italy as of April 25, 2020



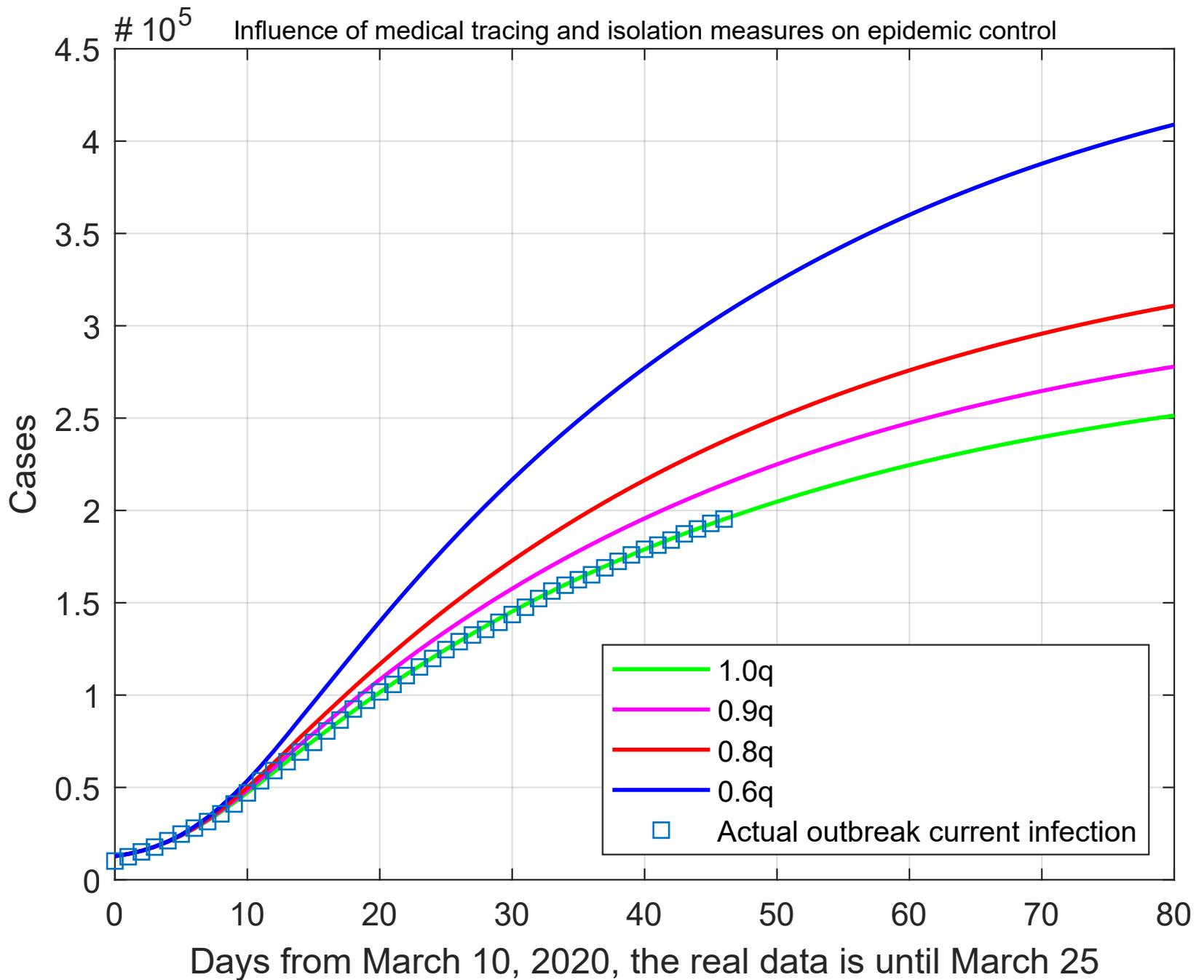




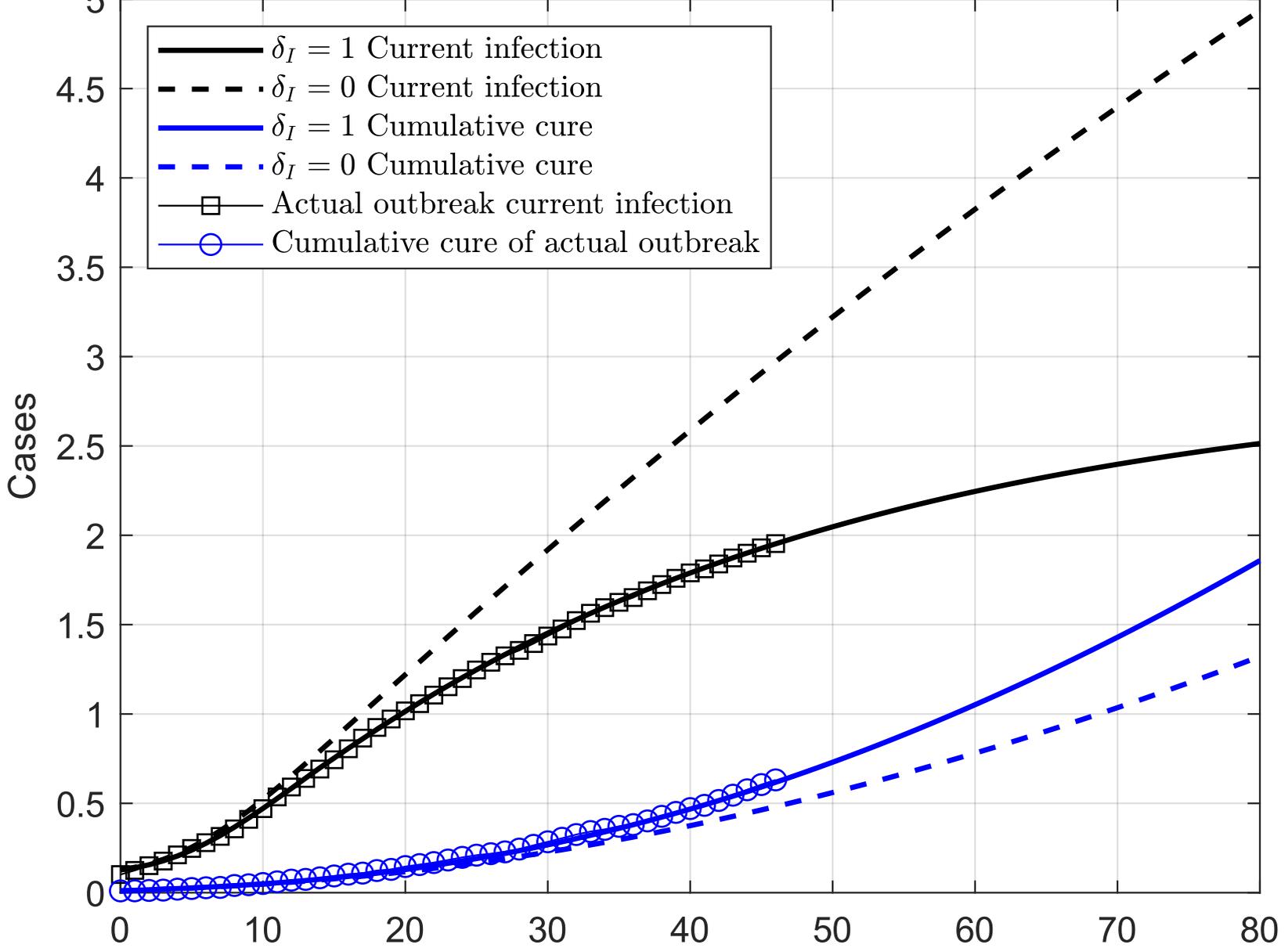
$\times 10^5$ Influence of prevention and control isolation measures on epidemic control



Days from March 10, 2020, the real data is until March 25



$\times 10^5$ Effect of centralized collection and treatment measures on epidemic control



Days from March 10, 2020, the real data is until March 25

